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AN INSTRUMENT FOR MEASURING THE SPECTRAL EMITTANCE OF A SOLID IN THE INFRARED FROM 16 TO 45 MICRONS AT LOW TEMPERATURES

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FOREWORD

The work described in this report was conducted in the Infrared Division, Research Department, Naval Ordnance Laboratory Corona, with funds supplied by the National Aeronautics and Space Administration Purchase Order No. W-11, 400-B.

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ABSTRACT

As part of a continuing research project for measuring the emittance of solids, a Beckman IR-3 spectrophotometer has been modified. This modification permits the measurement of spectral emittance of solids in the 16 to 45 μ region in the temperature range between 77 and 473°K.

INTRODUCTION

The theory, techniques, and experimental apparatus used in acquiring the spectral emittance of opaque and transparent solids in the 2 to 15μ region and in the temperature range between 313 and 453°K have been given in a previous report,[1] which described in detail the modification of a Beckman IR-3 spectrophotometer and the associated components that permitted these measurements.

Other modifications have permitted the measurement of spectral emittance in the 1.8 to 25μ region at temperatures from 313 to 473°K.

This report describes a second modification of the instrument, which permits spectral emittance measurements in the 16 to 45μ region and in the temperature range between 77 and 473°K.

MODIFIED EQUIPMENT

Figure 1 shows a diagram of the optical system of the unmodified IR-3. The gas cell and liquid cell were not required for this experiment and were removed; this eliminated lenses G and L and windows S and V. Figure 2 shows the optical system after the modification described in this report. In the monochromator compartment, the Littrow prism-mirror system (M and N on Figure 1) was replaced by a Bausch and Lomb replica grating; this grating, with 20 grooves per mm, has a 64 x 64 mm ruled area, and is blazed at 45μ. The full travel of the wavelength drive permits the grating to rotate through an angle of 18 deg; this rotation allows a spectral range from 16 to 45μ in the first order. The increased wavelength range covered by this modification required that the wavelength drive-gear train be reduced by a factor of 4. The other Littrow prism and mirror system (M' and N' on Figure 1) was replaced by a plane mirror. Lens K was replaced with a cesium iodide window; this is possible because the optical path is shortened by the elimination of the liquid and gas cell compartments. Lens Q was removed but not replaced with a window. The curved slits were replaced with straight slits that open to a maximum of 7 mm. The

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[1] NAVWEPS Report 7160, Infrared Spectral Emissivity of Optical Materials, by D. L. Stierwalt, 15 January 1961. (NOLC 537)

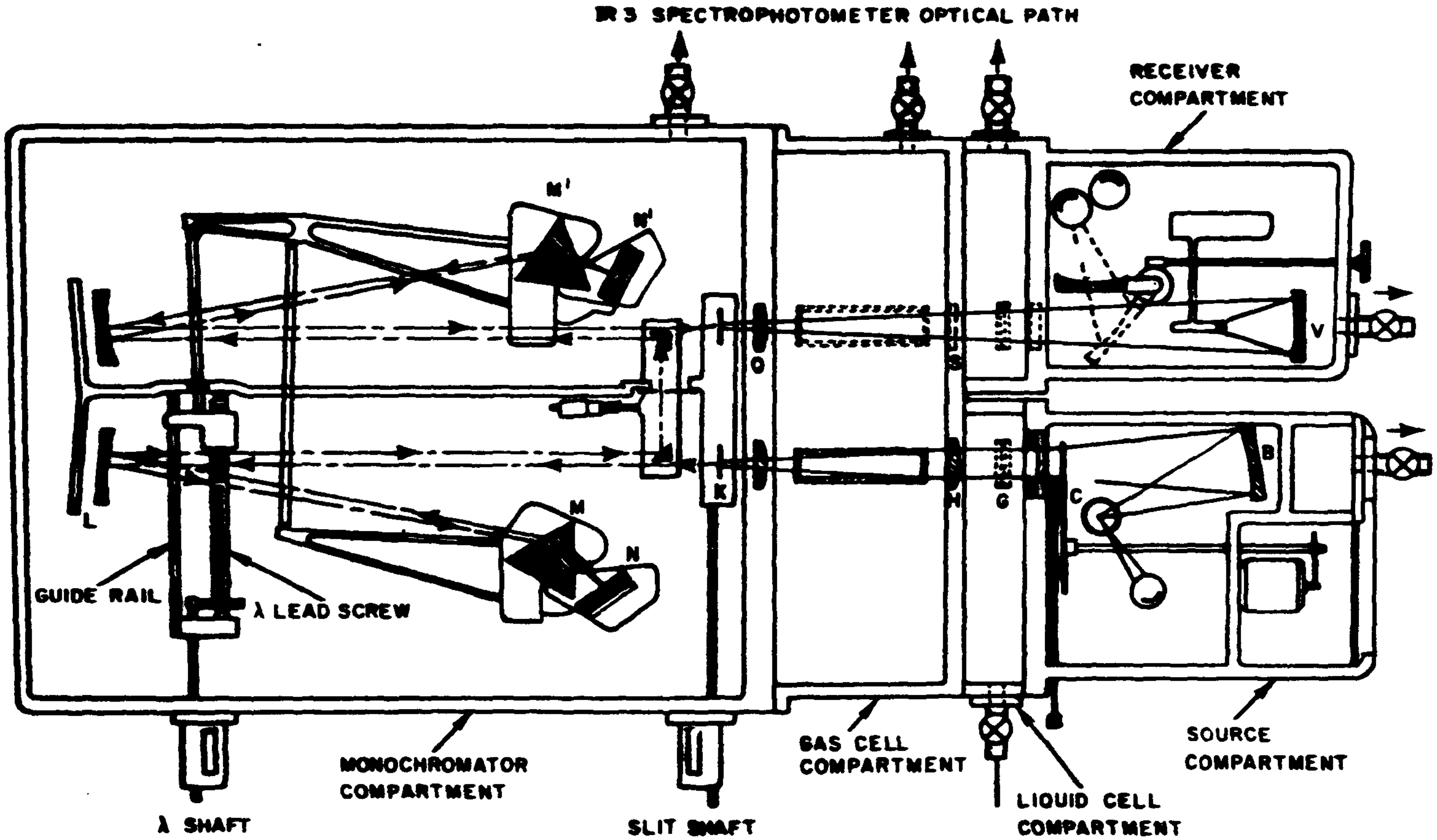

FIGURE 1. Unmodified Optical System

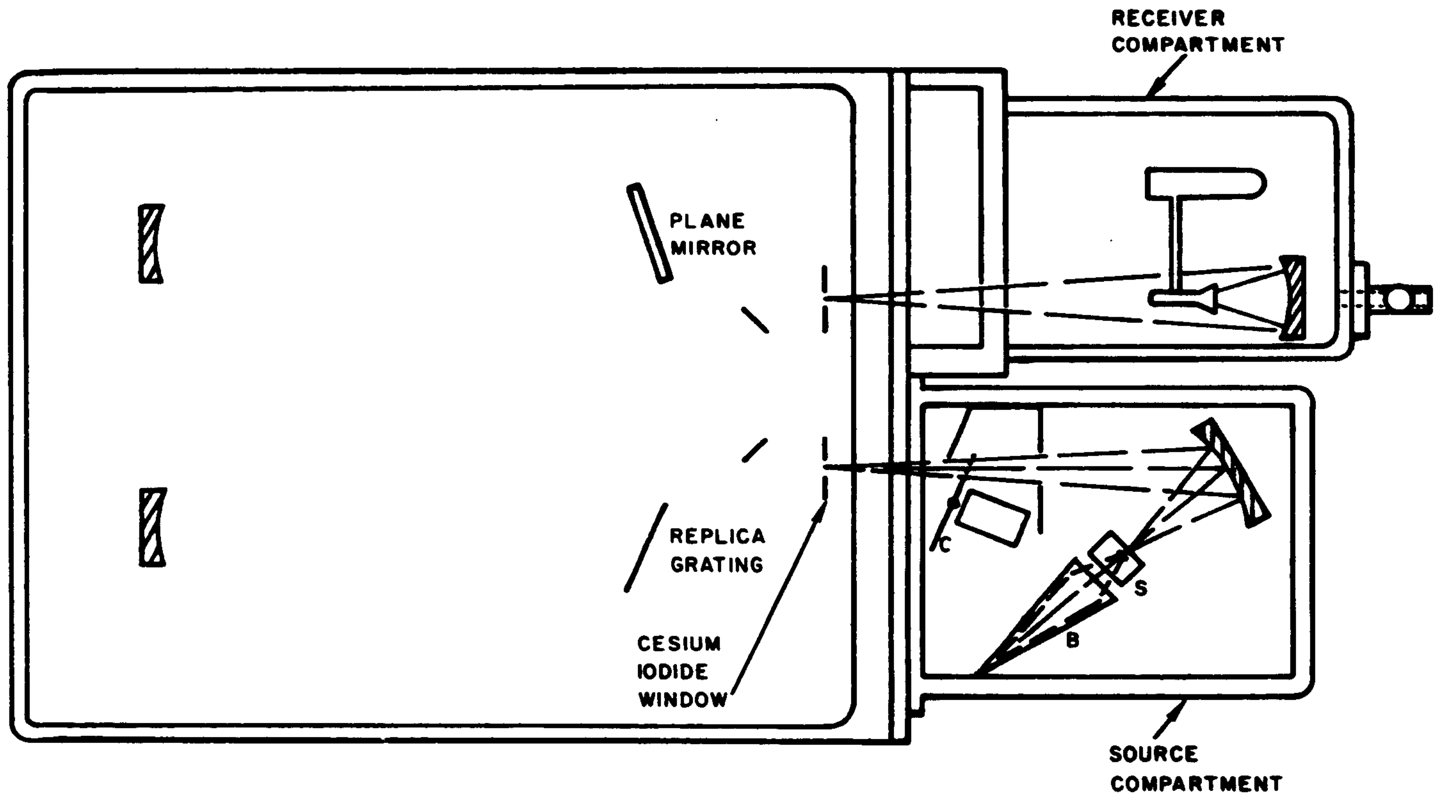

FIGURE 2. Optical System After Second Modification

selection of straight slits was made because in this energy-limited region where wide slits are necessary for obtaining relatively low resolution, little advantage can be gained from a curved slit.

The monochromator was calibrated by the use of a 6-6.5 μ bandpass filter and the 6.238 μ absorption line of polystyrene in the third to seventh orders. Since the calibration curve is nearly a straight line, these five points are sufficient to ensure accuracy of approximately 0.1 percent.

The source compartment was completely redesigned to permit the sample holder with sample to be inserted into the compartment at the end of a cold finger. Figure 3 is a cross-sectional view of the cold finger and sample holder. To keep thermal conduction low, the wall of the cold finger is stainless steel, 0.010 in. thick. Because the source compartment is evacuated, there is no need for a vacuum jacket around the cold finger. The sample holder with sample is inserted into the compartment in such a manner that one of the exposed sample faces is perpendicular to, and along the optical axis of, a concave mirror. This mirror focuses the energy of the sample on the entrance slit of the monochromator. The other exposed face of the sample (S on Figure 2) looks into a wedge-shaped blackbody (B on Figures 2 and 3) which is maintained at monochromator temperature. This blackbody provides a known background for transparent samples and also eliminates any radiation which might be reflected back through the sample. Other components of

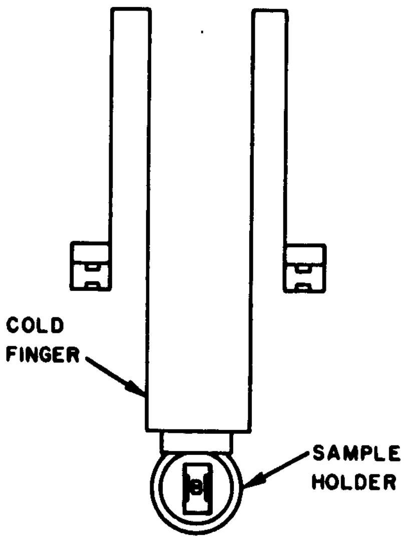

FIGURE 3. Cold Finger and Sample Holder, Cross Section

the compartment are a 10-cycle chopper (C on Figure 2), a reference cavity, and two bandpass filters.

One bandpass interference filter covers the region of 14 to 25μ; the other, 25 to 45μ. They can be manually adjusted from outside the source compartment at appropriate times during a measurement, to provide the proper order separation. Figure 4 shows the transmission characteristics of the filters.

The chopper has a mirror surface so that the radiation from the reference cavity enters the monochromator when the chopper interrupts the sample beam. If the reference cavity, background wedge, and sample chamber are kept at the same temperature as the monochromator, then only radiation emitted by the sample contributes to the ac signal at the detector.

For making transmission measurements, a Nernst glower can be used in place of the sample holder; the sample is then placed in front of the exit slit in the receiver compartment. The source compartment can be evacuated separately from the monochromator compartment.

Figure 5 shows the interior of the source compartment; Figure 6, the source compartment with the cold finger and sample holder in position for a measurement; and Figure 7, the cold finger with the blackbody in position in the sample holder.

In the receiver compartment, the photodetector and lead sulfide detectors were removed, and the thermocouple with a potassium bromide lens was replaced by a thermocouple with a cesium iodide lens.

The receiver and source compartments were joined directly to the monochromator compartment.

MEASUREMENT PROCEDURE

The previous report developed the general theory and presented a comparatively intricate method for reducing the acquired data. By utilizing a special case developed from the general theory, the method for reducing the data has been simplified. In most instances, a continuous record of the emittance can be obtained rather than a point-by-point result.

From the general theory, it was shown that in the special case where the blackbody temperature is the same as the sample temperature, the

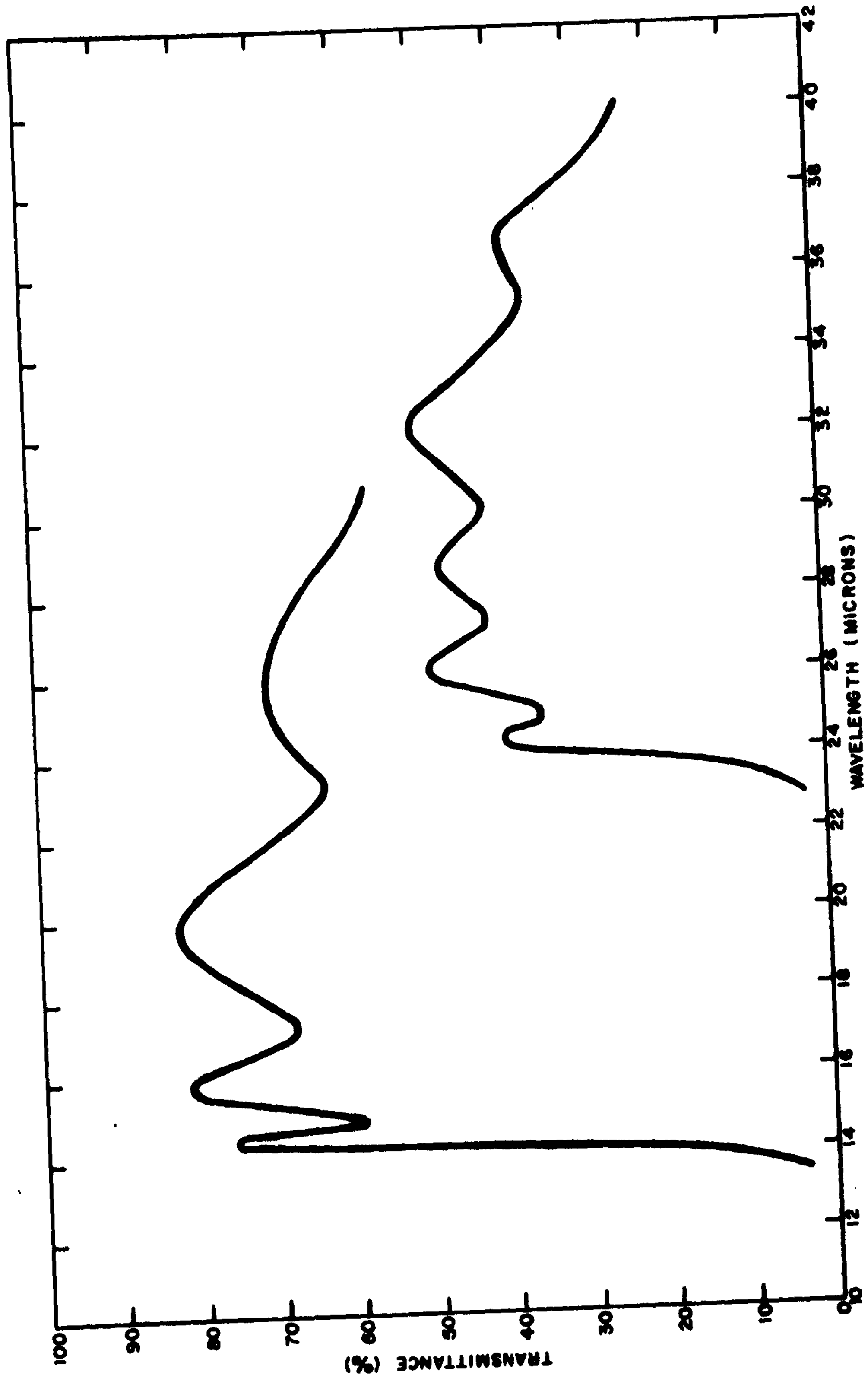

FIGURE 4. Transmission Characteristics of Bandpass Filters

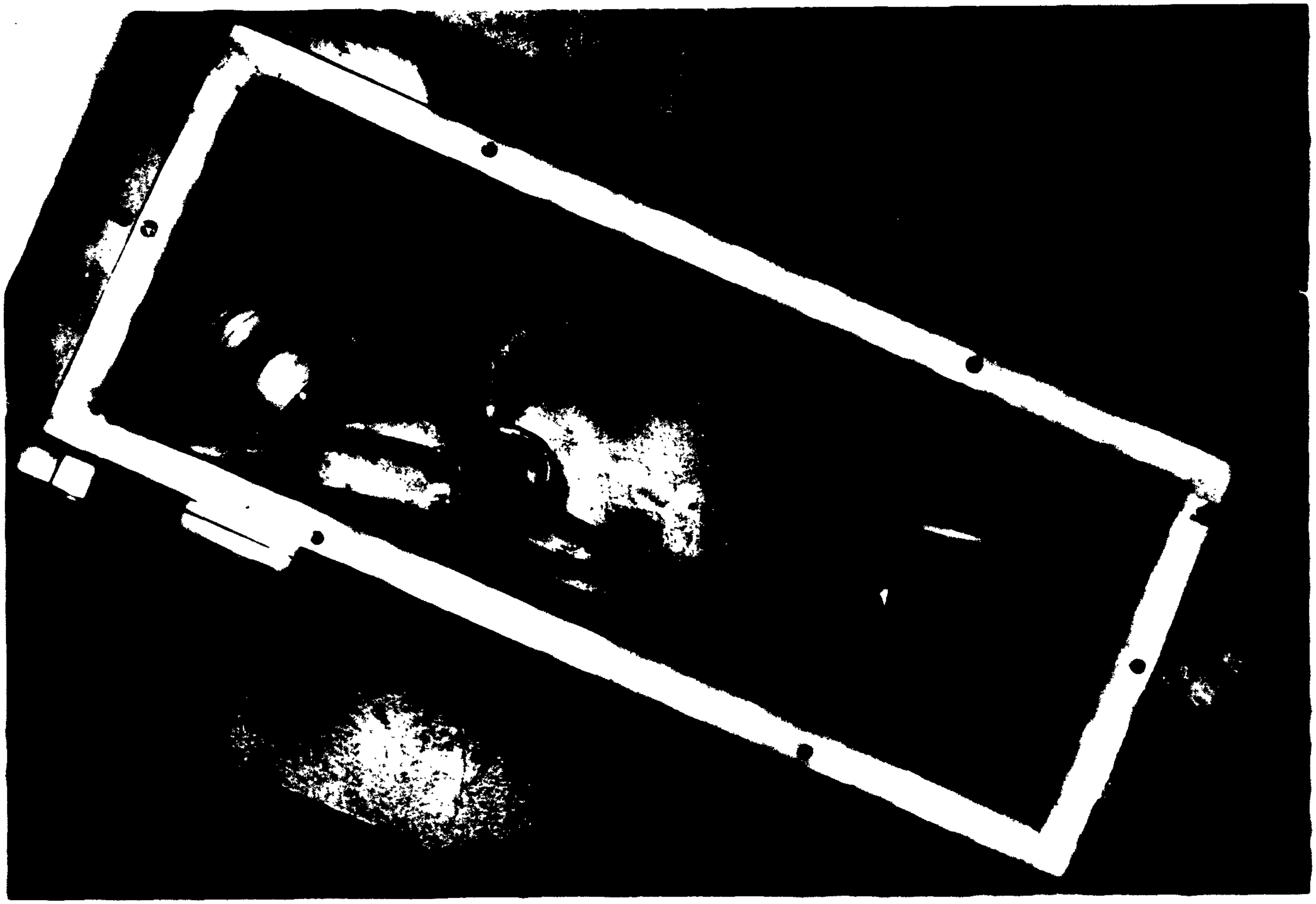

FIGURE 5. Source Compartment Interior

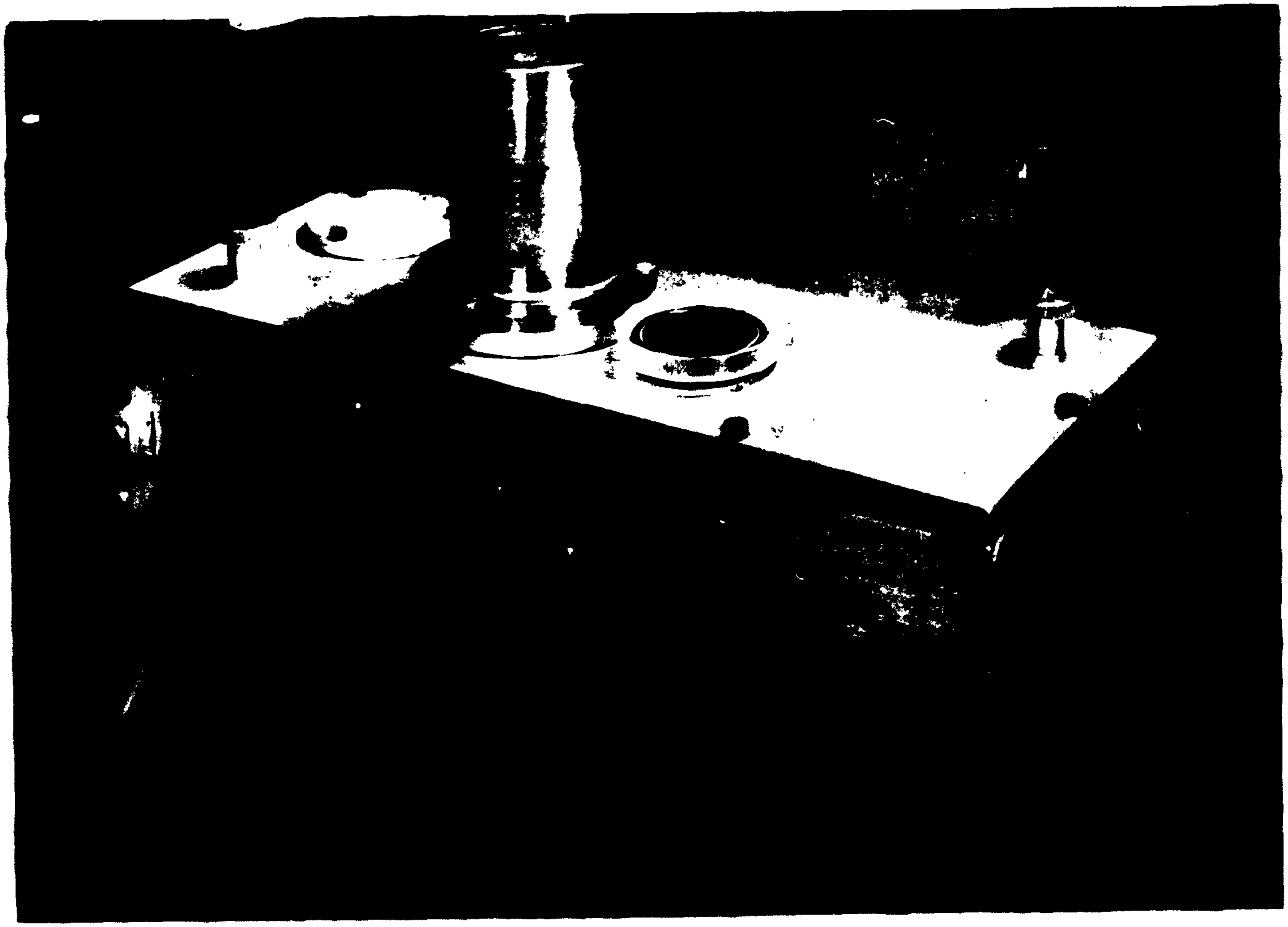

FIGURE 6. Source Compartment With Cold Finger and Sample Holder

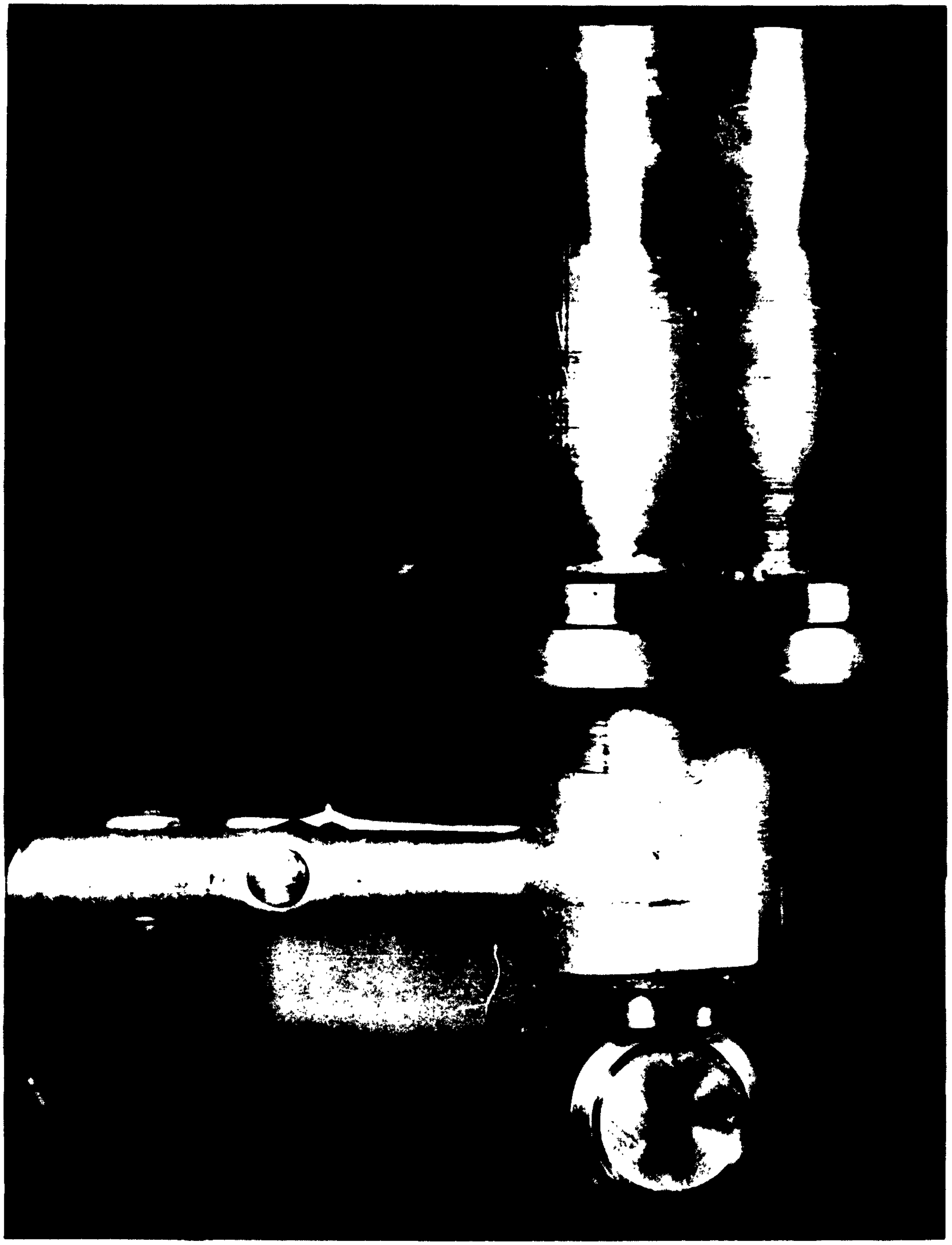

FIGURE 7. Cold Finger With Blackbody Inserted in Sample Holder

emittance of the sample is the ratio of the signal from the sample to the signal from the blackbody, or

$$e_s = \frac{S_s}{S_{bb}}$$

where

e_s = emittance of the sample

S_s = signal from the sample

S_{bb} = signal from the blackbody

This feature of the general theory can be applied to the instrumentation in the following manner: A blackbody is inserted into the sample holder and put in the source compartment in the same position as that of a sample. A standardization of this blackbody energy, over the spectral range and at the same temperature at which the sample's emittance is to be measured, is recorded on magnetic tape and on a chart recorder. The instrumentation is so devised that, during this standardization, a program of wavelength position as a function of slit width is recorded on the tape; this will permit examination of a constant energy to the detector in the spectral region. Where the energy from the blackbody is sufficient, the spectral region can be represented on the chart as a full scale deflection and designated 100 percent; when the sample energy is being tested, the recording on the chart is a direct, continuous reading of emittance.

In the regions where the energy from the blackbody is insufficient to give a full scale deflection, energy to the detector is not constant. The ratio of the energy obtained from the sample to that obtained from the blackbody can be read from the chart, thus giving a point-by-point measurement of the sample's emittance.

Some of the first measurements made with the modified instrumentation were on samples of cadmium sulfide and silicon at 77, 203, and 473°K. Figure 8 shows the spectral emittance of a sample of CdS approximately 4 mm thick at 77 and 203°K. Figure 9 shows the emittance of a sample of Si 2 mm thick measured at 77°K.

DISCUSSION

The purpose of this report is to show the further modifications to the Beckman IR-3 spectrophotometer that were necessary to extend the

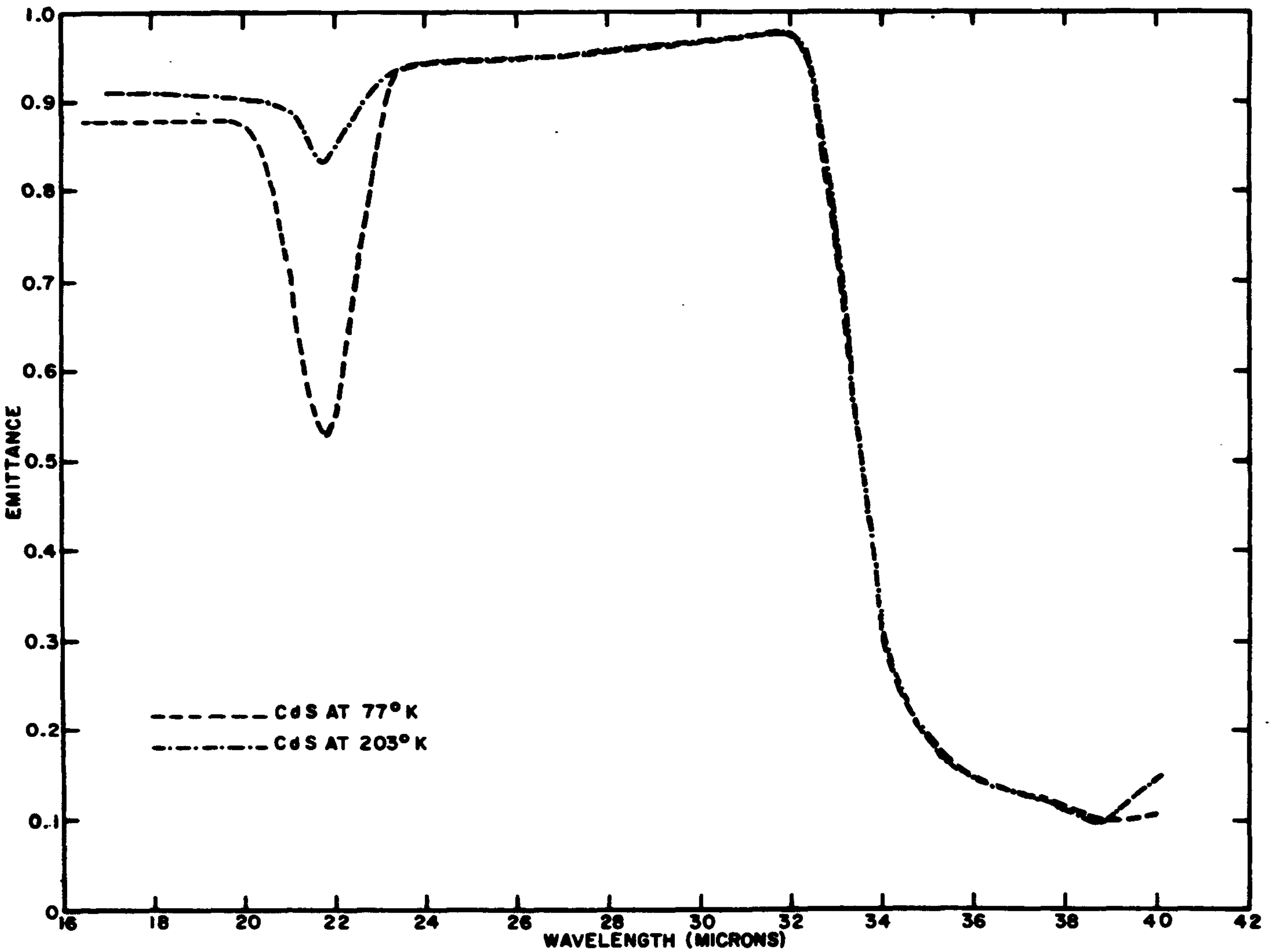

FIGURE 8. Spectral Emittance of a Cadmium Sulfide Sample 4 mm Thick

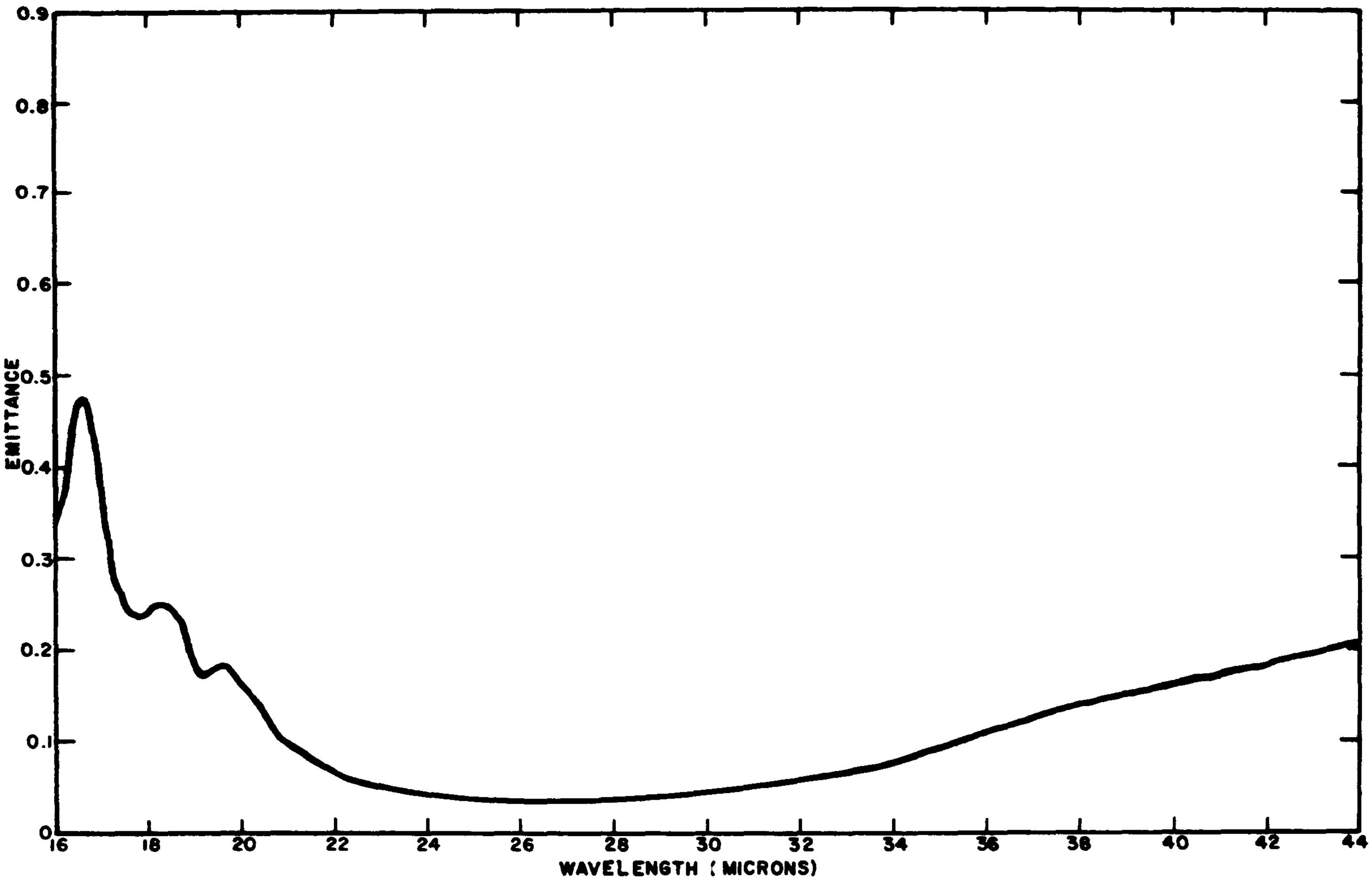

FIGURE 9. Spectral Emittance at 77°K of a Silicon Sample 2 mm Thick

spectral region and temperature range of the instrumentation discussed in the earlier report. Over this spectral region, CdS and Si exhibit high and low emittances, respectively; data from both are included to show the new capability of the instrument.

All the solids that were measured by the instrument before this modification will be measured again in the new spectral region that has been made available. The results of these measurements will be the subjects of future reports.

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